IMPLEMENTATION OF A USER-CENTERED APPROACH IN THE CREATION OF A SUPPLEMENTAL APPLICATION TO AUGMENT ANATOMY EDUCATION

A Thesis

Submitted to the Faculty

Of

Drexel University

By

Kristopher J. Connell

in partial fulfillment of the

requirements for the degree

of

Masters of Science in Digital Media

May 16, 2011

Dedication

I would like to dedicate this thesis to my parents. My mother, Sylvy, for always encouraging me to pursue my happiness, and my father, John, for always pushing me to do my best. Without them I would not be where I am today.

Acknowledgements

I would like to express my gratitude to the following people for all the help they gave me through this long process. First, I would like to thank my advisor David Mauriello for all the advice, time, and experience he gave to this project along the way. He is an outstanding teacher, providing an excess of encouragement and criticism, and always trying to drive his students to do their best.

I would also like to thank my committee, Dr. David Ebaugh and Jervis Thompson. Their wealth of knowledge and expertise were invaluable throughout this entire process.

I also want to recognize the other members of Drexel's Digital Media faculty who aided me in the process. Troy Finamore for his enthusiasm and eye for design during the initial phases of the application design. Also, Glen Muschio for his support, dedication, and guidance while developing this thesis.

A special thanks goes to my brother, Patrick Connell, for his help proofreading the paper and the wealth of information he continues to provide me, and to Lauren Scull, for her insight and endless encouragement during the entire process.

Table of Contents

List of Figures

Key Terms and Abbreviations

Animation Controllers: Objects attached to the characters which are used to facilitate the animation of the character.

Baking: (Animation) The process of assigning keyframes to each interpolated point in an animation.

CT: Computed Tomography

DICOM archive: Digital Imaging and Communications in Medicine.

FK (Forward Kinematics): A method of animating where each animation joint is articulated independently of the other joints in the hierarchy.

Frame: (animation/film) A single still image that makes up a movie/motion picture. Each frame is displayed for a fraction of a second.

Frame Rate (FPS): the number of frames per second (i.e. 24fps, 30fps, 60fps).

GUI: Graphical User Interface

HIPPA: Health Insurance Portability and Accountability Act

IK (Inverse Kinematics): A method of animation where the transformations of each animation joint in the defined kinematic chain are calculated based on the relationship between the rest of the joints in the chain.

IK Spline: An Inverse Kinematics animation setup where the joints in the kinematic chain are controlled by a curve system.

Joint Chain: A hierarchy of animation joints.

Keyframe: (Animation) The pose/image created by an animator. In computer animation, the computer calculates the transformation values between each keyframe to create motion.

Kinesiology: The study of human motion.

OBJ file: (Object file) A simple data-format that can be imported into a multitude of modeling packages. It represents 3D geometry by storing the position of each vertex, the face of each polygon, and the direction of the face normals.

Maya: A modeling/animation software by Autodesk.

MRI: Magnetic Resonance Imaging

OsiriX: An open-source PACS workstation DICOM viewer.

Normal: A vector that is perpendicular to the face of a polygon. The direction of the normal as it relates to the face it's attached to, the lights in the scene, and the camera in a 3D program affect how the polygon will look when rendered.

Normal Map: An image file created in a digital sculpting or modeling program manipulation program. This image contains a range of colors that will allow the render engine to bend the normal of each polygon, giving the illusion of additional detail with a low-density model.

PACS: picture archiving and communication system

Poly-count: Refers to the number of polygons contained in a model.

Polygon/Poly/Face: A term used in computer graphics used to define the individual shapes that make up a 3D model.

Retopologize: The process of restructuring the topology of a model

Rig: (animation) A representational “skeleton” used to deform and animate geometry

ROI: Standing for “Region of Interest,” it is the name of a toolset present in OsiriX that allows the user to trace and isolate areas in a DICOM archive.

Set Driven Key: (animation) an attribute assigned to an object that can influence another object in the scene

Texture Map: An image file exported from a digital painting/image manipulation program that contains the color information that will be rendered on the model.

Topology: (modeling) The structure/flow of the polygons that make up a model.

Abstract

Anatomy is a key knowledge domain for medical and healthcare professionals; it is also a key part of the foundation of knowledge for students studying within the medical field. Due to limited resources, institutions are looking to modern technological solutions to augment the traditional classroom experience. However, the current resources available to educators fail to fully meet the needs of students, and a user-centered design is essential to maximize the effectiveness of the resource and facilitate a meaningful learning experience. The purpose of my thesis is to produce the proof of concept for an interactive application to supplement traditional anatomy education. This application leverages digital media technologies and theory and was informed by educational and cognitive theories with the goal of improving the learning experience of the user.

Introduction

As a foundation of learning for medical and health professions, educators and students acknowledge that a thorough understanding of anatomy is vital. In depth understanding of how the body functions in health, and how that function is altered by disease or injury, is critical for proper diagnosis and treatment[1, 2]. Because the study of health and medicine relies so heavily on the foundation of human anatomy, the process, curricula, and resources that establish this foundation warrant close and thorough examination.

Despite advances in technology and learning over the past several decades, the resources used by medical and colligate institutions to teach anatomy are limited. These resources typically include cadaveric specimens and various textbooks. However, since these resources are static mediums, they have difficulty adequately portraying motion, which required for students to properly understand the concepts of joint motion and muscle function.

While efforts have been made in some curricula to incorporate interactive media solutions to enhance learning, these efforts are not fully comprehensive nor user friendly [2]. While many contemporary resources provide strong visuals and accurate information about structural anatomy, their designs lack some pieces necessary for complete understanding of muscle function. These applications restrict the level of user control over the joint motion and muscle deformation, and do not adequately portray the multiple types of muscle contraction which occur in human motion [3, 4].

This thesis sought to address this discrepancy by producing an interactive 3D application intended to supplement the teaching of anatomy. Specifically, this project is intended as a proof of concept for an application to improve a student's overall learning experience and enhance their understanding joint motion and muscle function. Basic research on the creation of the application was informed and directed by Dr. David Ebaugh, an assistant professor in the Department of Physical Therapy and Rehabilitation Sciences with Drexel University's College of Nursing and Health Professions.

In modern medical education, cadaver dissection remains the best method for teaching human gross anatomy [2]. Cadaver dissection exercises provide students with hands-on opportunities to observe, study, and learn the different aspects of human anatomy including the construction and workings of the skin, muscles, bones and joints. Studying in a cadaver lab provides students and health care professionals with invaluable experiences regarding the nature and function of the human body.

Unfortunately, cadaver labs are both difficult and costly to update and maintain. Preserving cadavers is a demanding, hazardous, and costly process. The problem is made more complex by the increasing number of medical institutions, creating competition for available cadavers, compounded by a general shortage of cadavers due to limited donations. To address the problem, medical educators and professionals are looking to modern technological solutions to augment the cadaver lab experience [2].

There are a multitude of resources available to students that supplement traditional cadaver lab learning experiences. Educators hope these materials will strengthen student's understanding of difficult concepts. An area of particular difficultly is understanding muscle function, where resources available to students primarily consist of text books with 2D images and text. Although interactive applications exist, the majority of available applications only provide a static 3D model with text. Neither method provides an optimal environment for understanding and learning about human motion. Even cadaver labs, the gold standard in anatomical education, are deficient in this area since this form of learning does not allow students to see muscles contract and observe the body in motion. Even with access to the best available resources, students are forced to struggle with understanding the concepts of muscle function, making an already difficult area of study more complex [3-7].

In order to facilitate an optimal learning experience, information must not only be presented in a way that provides a meaningful experience, it must promote active reflection on that information. Resources created for such educational purposes should be created with a learner-centered approach [1]. With a multimedia application, serious consideration must be given to what medium will be used to display the information. The material should be communicated through multiple mediums to accommodate different types of learners. Some users learn better with written or verbal information, while others benefit more from visual information. However, vividness in presentation will not increase the effectiveness of learning. If too many forms of media are presented to the user at once, the educational experience may be hindered. Designers must balance the presentation of information with the abilities of the users. Also, the quality of learning is not limited to the initial experience. For deep learning to occur, meaningful reflection must also take place [8]. In creating this type of application, it is important to provide both a meaningful experience for the user, and a tool to aid in meaningful reflection on the information they learn.

This thesis employed a user-centered design process to maximize the effectiveness of the application and hopefully provide a meaningful learning experience for the user. This process utilized the latest media technologies to present an intuitive tool that allows the user to tailor the experience to fit their individual learning style. This combination of ideas will facilitate the creation of an interactive application designed to augment anatomy education.

Background Information

A user-centered approach is critical when creating an educational application. A designer must realize that not all people learn the same way. In Nigel Cross' article *Styles of Learning, Designing, and Computing*, he discusses how people have different cognitive styles that they implement in the learning process. He categorizes these styles and divides them into 3 different pairs: serialistic vs. holistic, convergent vs. divergent, and focused vs. flexible. The first pair categorizes how different learners proceed through a problem. Serialistic learners prefer to work in small, logical steps, progressing in a straight path, and attempting to comprehend and solve each piece before continuing while avoiding any digressions (Figure 1A). Holists work on a broader scope (Figure 1B). As they complete each piece, they progress to a topic that may only be tangentially connected to the current problem. Convergent vs. divergent thinkers differ on the type of answer they are searching for. Convergent thinkers (Figure 1C) take information and come to a single, in depth, correct answer, whereas divergent thinkers (Figure 1D) are looking for an 'open ended' answer to the question. Divergent thinkers place more of an emphasis on their ability to generate a wide range of answers. Lastly, Cross discusses focused vs. flexible thinking, which describes how people will approach a problem. Focused thinkers, like Serialists, proceed in a linear, logical manner, taking the most logical route to solve the problem (Figure 1E). Flexible thinkers are able to progress in less logical paths. They will examine a problem and come at it from an entirely different angle, thinking outside the box (Figure 1F) [9].

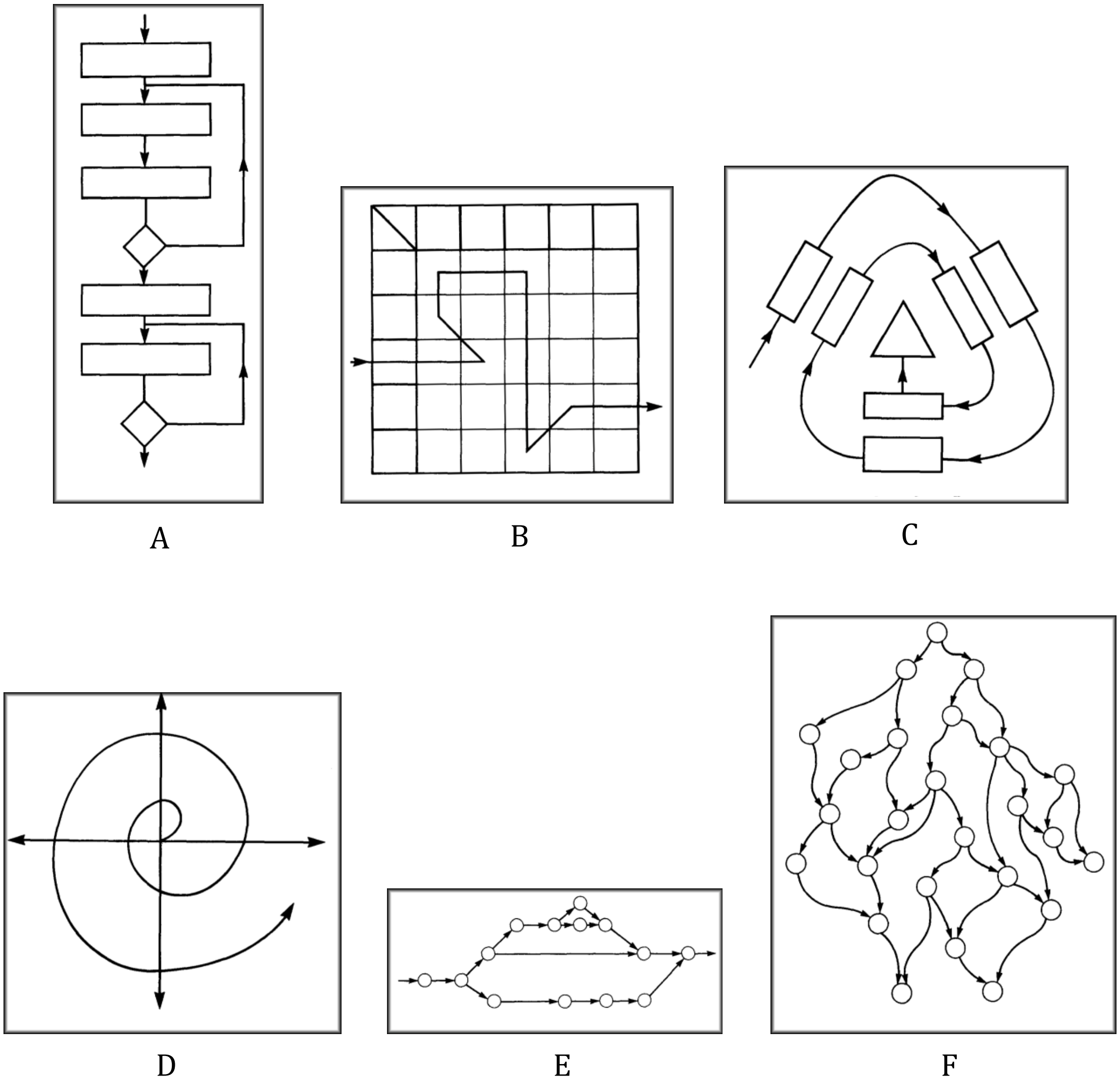


Figure 1: Diagramed representations of Thinker/Learner Types

A) Serialistic **B)** Holistic **C)** Convergent

D) Divergent **E)** Focused **F)** Flexible

In *Interactive Multimedia and Learning: Realizing the Benefits*, Sandra Cairncross and Mike Mannion specifically discuss elements a designer should consider while creating an interactive multimedia project. They discuss how advances in media technology can be used to create a more integrated, enhanced learning. However, a designer must be cautious how they implement the multimedia technology. Vividness of presentation does not automatically lead to better learning. Presenting the user with too much visual stimulation can cause problems such as memory overload, divided attention, and disorientation. Those problems will make the learning experience ineffective [10].

If presented correctly, those same pieces of media can create a meaningful experience. Like Cross, Carincross and Mannion discuss how people learn and process information differently, specifically that some learners respond better to different types of media. For example, "verbalizers" prefer information represented through words, either text or audibly spoken, while "imagers" prefer information in a visual format, such as images or video. Successful learning applications will give the user the option to display information in their preferred media type. Using various media types also engages multiple senses and reinforces the information, providing a redundancy effect that aids the transfer of information from short to long term memory [10].

To inform the design of an application, there needs to be an understanding of how people learn and process information. One educational concept is called experiential learning. It was formed by John Dewey when he devised the idea of "experience plus reflection equals learning" in the 1930's. This challenged the traditional, teacher-centered system of that time and placed the focus on the user. Dewey described the quality of a learning experience as a combination of the factors and knowledge before, during, and after the experience. His work focused mainly on the experience, viewing reflection as a natural process that occurs while quietly contemplating the activity. According to Dewey, in order to have meaningful learning, an experience must consist of equal parts learning and reflection [8]. This relationship between experience and reflection is displayed in Figure 2.

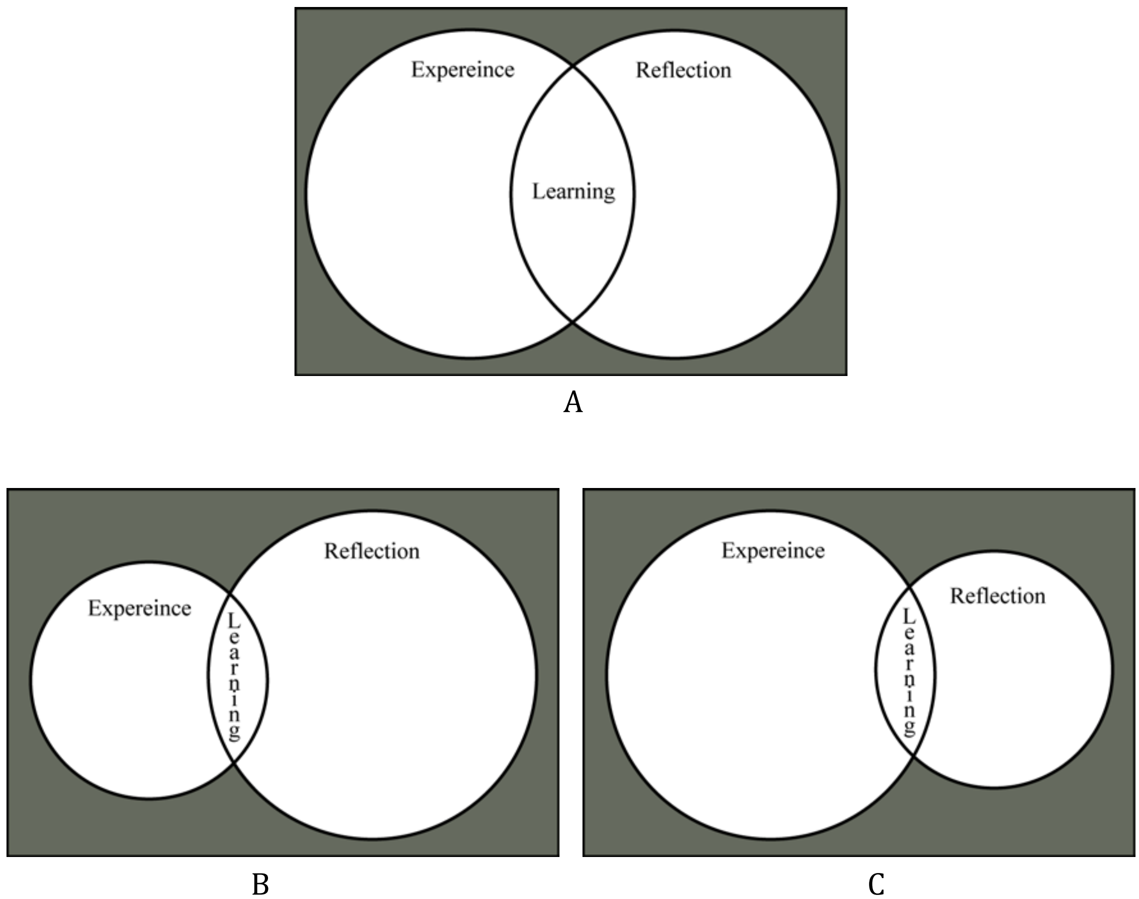


Figure 2: Experience/Reflection/Learning Relationship

A) Experience = Reflection **B)** Experience < Reflection **C)** Experience > Reflection

Another major figure in experiential learning was David Kolb, who thought learning came from the full comprehension and transformation of an experience. His learning process is a cycle consisting of the Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation (shown below in Figure 3). This cycle consist of two opposing aspects. The Concrete Experience and Abstract Conceptualization compose the ‘prehension’ dimension of learning, and the Reflective Observation and Active Experimentation comprise the ‘transformation’ dimension. Kolb proposes that meaningful learning stems from the resolution between these elements [8].

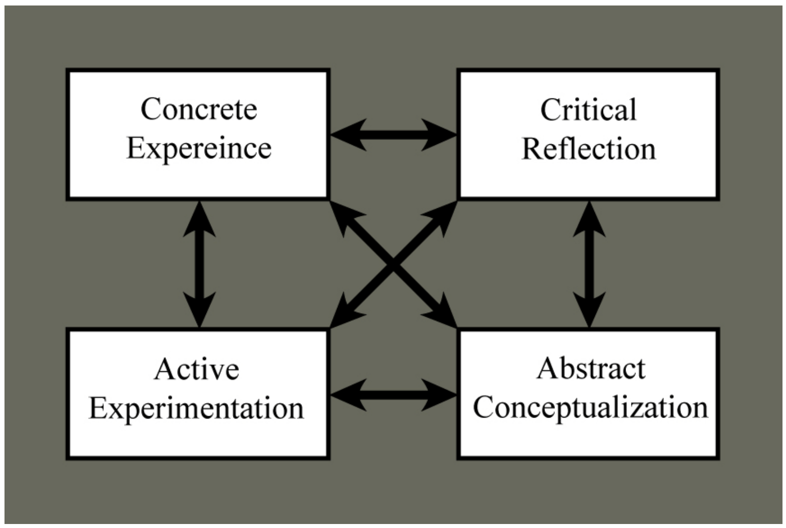


Figure 3: Diagram Displaying Kolb’s Concept of Experiential Learning

Another learning theory to be considered is the Cognitive Load Theory. The basic premise of this theory stems from the limitations of the human brain, namely that a person can only process a limited amount of information at once. In order to have meaningful learning, the information presented cannot exceed the learner’s cognitive load. A persons cognitive load can be alleviated through several factors based on the preparation of the learner and the resources available to them (Figure 4). A well designed educational application facilitates the learning process by easeing some of the task demands. John Sweller discusses this concept in his article *Cognitive Load Theory, Learning Difficulty, and Instructional Design*.

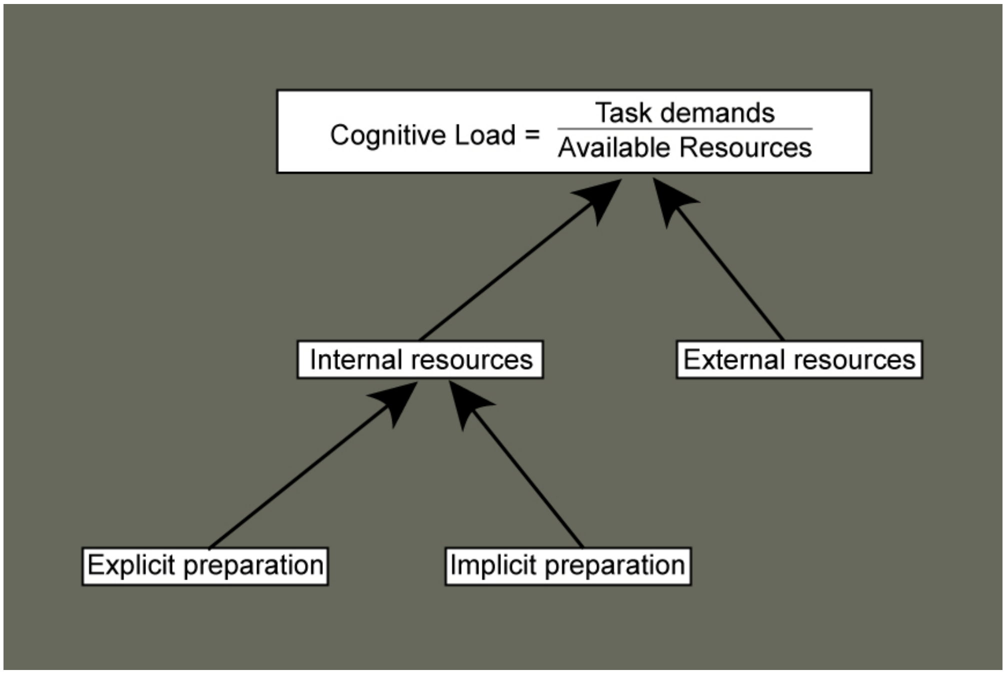


Figure 4: Cognitive Load Theory- Alleviating Task Demands

He discusses two mechanisms critical to intellectual mastery: schema acquisition and automation of intellectual operations. A schema is a cognitive tool that allows elements to be organized into a single group, aiding the mental process. Instead of being forced to use cognitive energy to focus on each individual aspect, the work is greatly diminished since the pieces have been stored as a single entity. Automation of intellectual operations also allows the cognitive load to be diminished. Instead of actively focusing on certain elements, processing of the information contained with the elements can be automatic. For example, when a literate person reads a paper, the process of deciphering words is automated. They do not need to expend the effort to understand the meaning of a word, and can spend their energy interpreting the paper. These mechanisms aid a learner by reducing their overall cognitive load. Any learning experience must be designed to keep the user's cognitive load within manageable levels [11].

James Paul Gee should also be considered when designing an educational tool in this era of media technology. His work, *What Video Games Have To Teach Us About Learning and Literacy,* examines the learning model intrinsically contained in any good video game. He noted that well designed video games are very complex and challenging, yet people both enjoy and are quite successful in completing the tasks presented in the game. This success is not limited to any specific type of person. Players from any social or educational background can play these games. Even high school students who perform poorly in the classroom can succeed at a game that challenges an adult with multiple college degrees. Gee studied these games to determine what they possess that traditional educational techniques lack.

Gee outlines 36 Learning Principles that are built into good video games. While all of those principles are important, there are a few key principles to consider when designing an interactive application. First is the Active, Critical Learning Principle. The designer or teacher must ensure all aspects of their learning environment establish and encourage active and critical learning. In traditional education, students are just presented with information. Instead, the learners should be engaged and participate in the learning activity. Gee's Semiotic Principle states that realizing the interrelations in and across sign systems is core to the learning experience. A learner must be able to discern meaning from any intelligible combination of images, words, actions, or other symbols.

Several of his principles are in relation to how users approach learning tasks and practice, a crucial concept in a supplemental application. The "Psychosocial Moratorium" Principle states that learners profit from an environment where consequences of experimenting and pursuing lines of intrigue are lowered. According to the Achievement Principle, people want to be rewarded as they accomplish goals and overcome challenges. If the risks are too high and their accomplishments are not acknowledged, users will not put forth the effort to continue the task. All of these principles are incorporated into successful video games, and in Gee's opinion, are what leads to their success [12].

Based on these educational theories and cognitive concepts it appears that there is a need to re-evaluate the current way multimedia educational applications are designed. These applications do not fully leverage the power of digital media and technology in order to create a learning environment with all of the aforementioned concepts in mind. By designing an interface that will create a meaningful and reflective learning environment, accommodate a wide range of learner types, and exploit digital media's ability to combine visuals, text, and motion, an application can be created that will push the boundaries of educational design.

Methodology

In designing this application, there were three main areas of consideration during the production process, the design of the application itself, the creation of the content for the application, i.e. the musculoskeletal model, and the integration of the 3D anatomical visual into the application.

Application Design

In the creation of any interactive experience, careful consideration must be given to the creation of the interface in order to ensure an enjoyable and meaningful user experience. Since this application is meant to be an educational tool, the interface not only had to be intuitive for the target audience, but special attention was given to ensure that information was communicated properly and held to a high level of accuracy.

To ensure the application was designed with the user (anatomy students and medical professionals) in mind, Dr. Ebaugh, a professor from Drexel University's College of Nursing and Health Professions, was consulted. His input provided crucial insight into the realm of anatomy and his expertise ensured that the information presented in the application is clear and accurate.

The first step was to determine what program and coding language I would use to create my application. After researching some of the available programs, I decided to use the Unity 3 game engine to create my application. Unity 3 is a powerful tool with strong support documentation and a vast support community that could be accessed during the design process. The engine also includes methods that allow for easy expansion to additional platforms (Andriod, iOS, etc.).

Once that decision was made, the next stage was to establish the major pieces of functionality that would need to be included in the interface. Before the Graphical User Interface(GUI) was created, it was important to determine the appropriate design criteria to ensure an intuitive interface. The most basic type of functionality that must be available in any application is the ability for the user to navigate the space. Since the focal point of the app is to study a 3D model, the user must be able to pan, rotate, and zoom. This gives the user freedom to focus on any piece of the body and view it at the desired angle.

Since I am designing for this app a wide range of users, I designed two interaction methods that would allow the user to navigate the application. The most common way to navigate a 3D space is to provide a set of key/mouse commands that will allow the user to simply click in main stage of the app and adjust their perspective (Figure 4). However, since the audience I am designing for may not be very familiar or comfortable navigating a virtual 3D space in that manner, I decided to also include a system of button navigation, where the user can click a button to pan, zoom, or rotate around the object instead (Figure 5).

Figure 5: Graphic from the Application's Help Screen Displaying the Mouse Navigation Commands

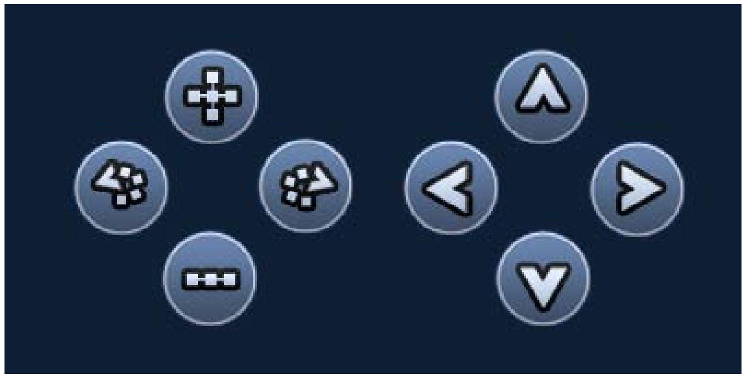


Figure 6: The Icons for the Button Navigation included in the application

To allow for ease of use, I also built a navigation system into the interface that would allow the user to click on a region of the body on the navigation window and the camera would jump to that region. I added this piece so that the user could easily jump from area to area, without having to worry about navigating the 3D. Along that same vein, I added a button to the navigation tab that rests the entire application into its default position, including the body pose. This allows the user to easily return to a neutral position and begin studying another aspect of the body.

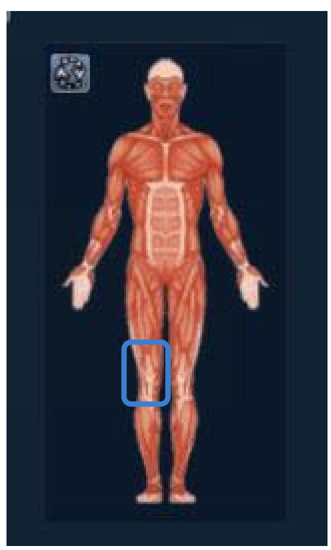


Figure 7: Body Navigation With Reset Button

Another major piece of functionality is the user's ability to select the various parts of the body they are attempting to study. I designed a system of flags which correspond to each muscle that the user could toggle on or off. This allows the user to easily choose the muscle they are interested in, but gives them the ability to disable that functionality so it does not interfere with navigation in the application or obstruct the view of other anatomical structures. In selecting one of these flags, a small tab pops up that gives the name of the muscle and allows the user to adjust its opacity, in case it is obstructing their view of the muscles around it. The user also has the option to open a new menu tab that displays information relevant to that particular anatomical structure, such as the origin, insertion, and actions of a muscle.

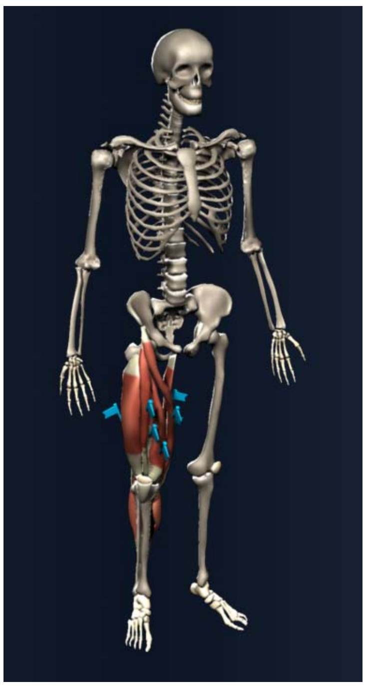


Figure 8: Leg Model With Info Flags

In addition to selecting a particular muscle with the flag, the user can click on a joint and gain the ability to use sliders to move that joint. The number of sliders that appear is based on the degrees of freedom of the specific joint selected. Each slider will reflect the medical terminology for motion (ex. flexion and extension, abduction and adduction) appropriate for that joint. For example, the knee would have one slider, labeled with extension and flexion, since its primary motion is around one axis as shown in Figure 8. Providing a separate slider for each degree of freedom available serves several purposes. First, it limits this piece of functionality. The movement of each joint will be limited to a single slider per axis of motion, allowing the user to easily transition through the entire range of motion. Also, by labeling the axis with their proper anatomical terms, we are communicating the control in a language suited to the intended audience, as well as reinforcing the meaning of these terms. This will allow the user to more easily isolate the elements involved in the motion they are attempting to study.

Figure 9: Joint Manipulation Window

Second, working in tandem with the movement of the joints, a color indicator will be implemented to display muscle contraction. As the joint moves, the muscles responsible for that motion will change color, one color for concentric contractions one for isometric, and another for eccentric (shown below in Figure 9 A-C). This color shift will provide a clear visual cue to the user.

A B C

Figure 10: Muscle Contraction Color Indication

A) Concentric Contraction **B)** Isometric Contraction **C)** Eccentric Contraction

The final piece of functionality will allow the user to view different layers of muscles. Since the student's goal in anatomy education is to learn the function of each muscle, it is important that they are able to view each layer of muscle as it contracts.

Once I established the necessary functionality aspects, I designed and implemented the GUI. Since the key piece of the application is the 3D anatomical visual, I wanted the design to reflect that and make it the body the focal point. To do this, I focused on keeping the GUI pieces minimal and using color to accentuate the 3D model, making it stand out from the background. In my initial concept for the GUI (Figure 6), I created a fixed set of GUI pieces which framed the main viewer window in the center. Since the anatomical model consists of mostly warm and light colors, i.e. red/orange and beige, I used a mostly neutral color palette with blue accents in order to avoid competing with the main visual in the window.

As the application evolved, the GUI windows became less prevalent. Through various design drafts, I made aspects of the interface, such as buttons and sliders, smaller and gave the user the ability to toggle the items such as the information tab on and off and drag windows, placing them where they may be convenient. In addition to making the windows mobile, they were also made semi-transparent, so the user can see the model at all times, even when windows may be overlaid.

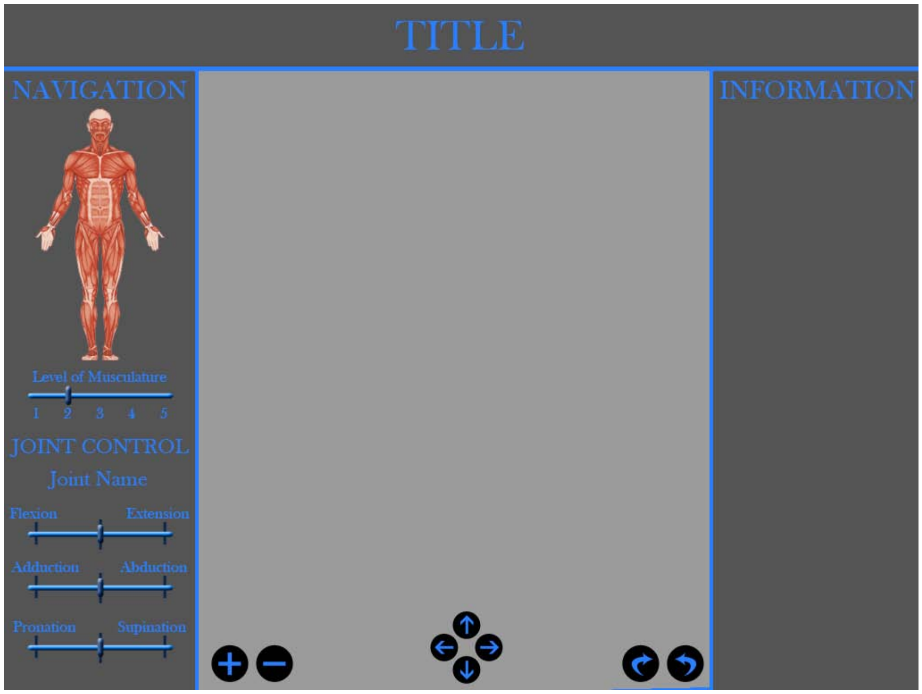


Figure 11: Initial GUI Concept

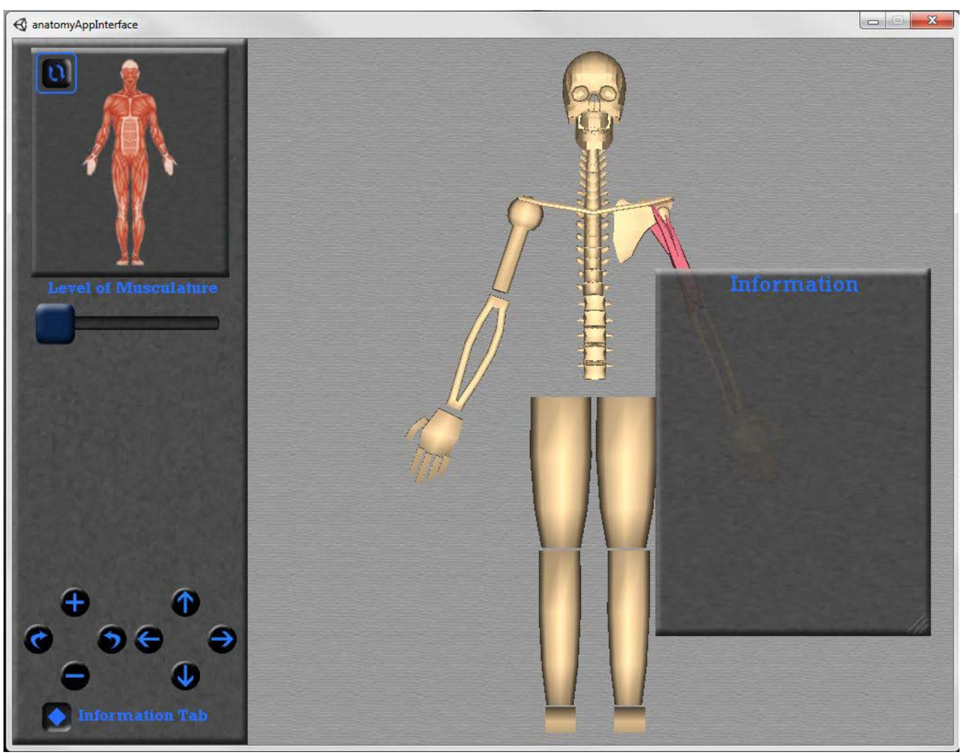


Figure 12: Intermediate GUI Concept

In the final iteration of the GUI design, this developed further so that all aspects of the interface are hidden until the user either selects a piece of the anatomical model or clicks one of four buttons placed in the corners of the application window. This gives the user to the ability to navigate and control the application when they need to, but will allow the important visual to take up the entire screen without being obstructed by windows. The color scheme of the entire GUI also shifted into a range of blues, giving the application a more dynamic look which further accentuated the contrast between the model and the rest of the application (Figure 11, 12).

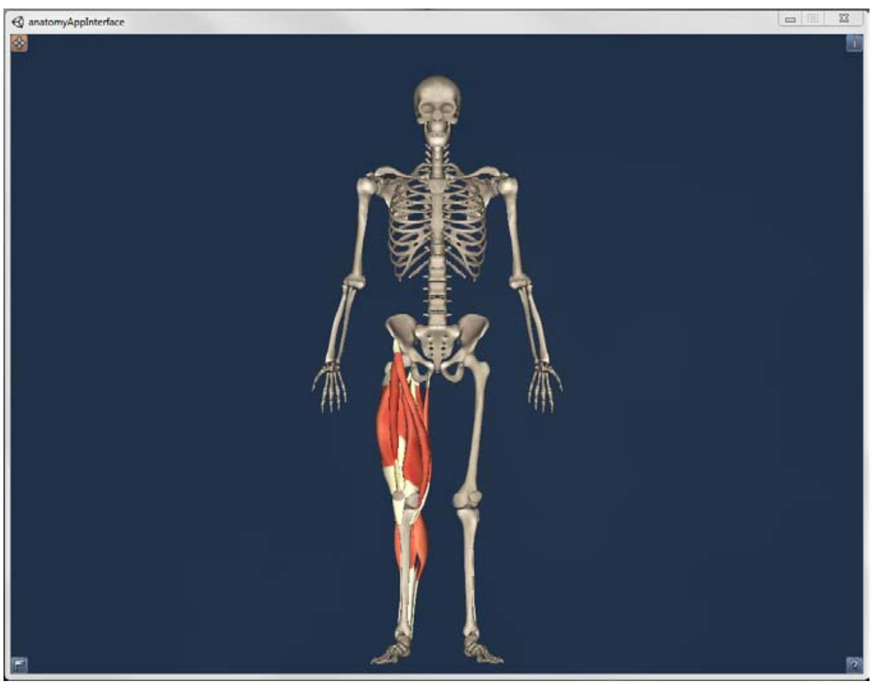


Figure 13: Final GUI Concept (Closed)

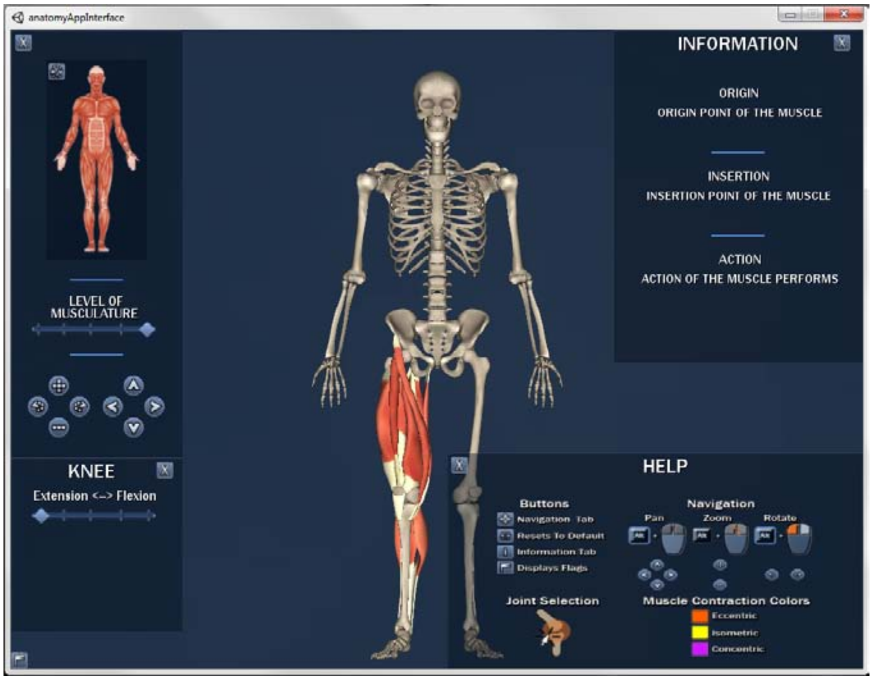


Figure 14: Final GUI Concept (Windows Open)

Anatomical Content Creation

To create a successful educational application, I needed to ensure not only an intuitive interface but also accurate anatomical visuals. To ensure accuracy, the bone and muscle models in the application were be derived from a set of CT scans available for download on the OsiriX website [13]. The scans I obtained had all personal or identifying information removed from them, and thus complied with HIPPA regulations. Acquired data, was imported into the OsiriX software, an open-source PACS workstation DICOM viewer for the Apple Operating System. OsiriX can read in the scans from the DICOM archive and by implementing a variety of tools built into the software, I was able to construct a 3-dimensional model of the various anatomical body parts I needed and export them as individual OBJ files.

To render out the models from OsiriX, I needed to utilize their 3D Surface Rendering tool. In order to translate the series of CT slice from 2D images into a 3D model, the program used a set of user-inputted values to render the volume based on iso-contours. The calculations of the iso-contours are "based on the direct computation of image space curves of constant intensity" [14]. In short, the program calculates a set of curves based on the particular intensity of an image. When dealing with CT scan images, this means that since a given point of intensity in a CT scan is based on the density of the material, the iso-contour render will isolate a set of curves/model based on a given density. This method worked quickly to extract the bones from the CT scans. Since bones are of a vastly different density from the surrounding soft tissue, it is easy to isolate them and extract the skeletal structure with little interference (Figure 13).

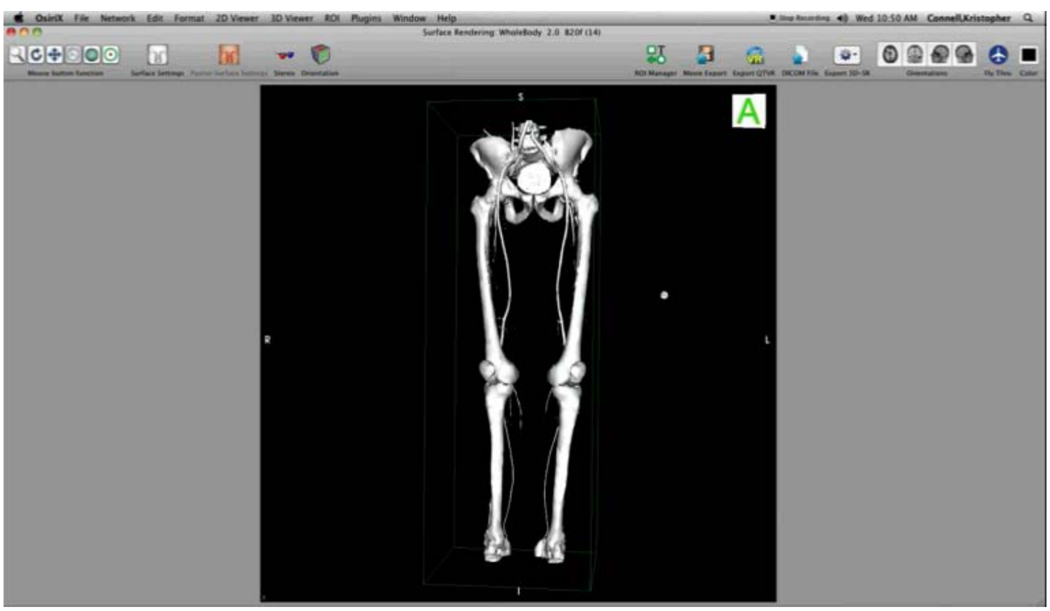


Figure 15: OsiriX 3D Surface Render - Lower Leg Bones

However, a problem arose when I tried to isolate muscle structures using the OsiriX software. Since all of the calculations OsiriX used to construct and render structures with the 3D Surface Renderer were based off a particular intensity/density range, the muscles, which are composed of tissues of equal density and tightly packed together, were rendered out as one giant mass. This resulted in most muscles being indistinguishable from one another.

To solve this problem, I was able to leverage the ROI tool in OsiriX to examine the CT scans and visually isolate individual muscle bodies. The ROI tool allows the user to trace an area of interest on a CT at various slice intervals (Figure 16A). The software will then interpolate the transformation of the ROI between each user generated curve. Once that ROI series is obtained, the intensity values of the images in the DIOCM set can be manipulated. In my case, I was able to set those values to black. This meant when the 3D Surface Renderer calculated the iso-contours, the only intensity values in the image were those of the muscle I wanted to render (Figure 16B), and the software was easily able to generate the model (Figure 16C). I then repeated the process for the remaining muscles [15].

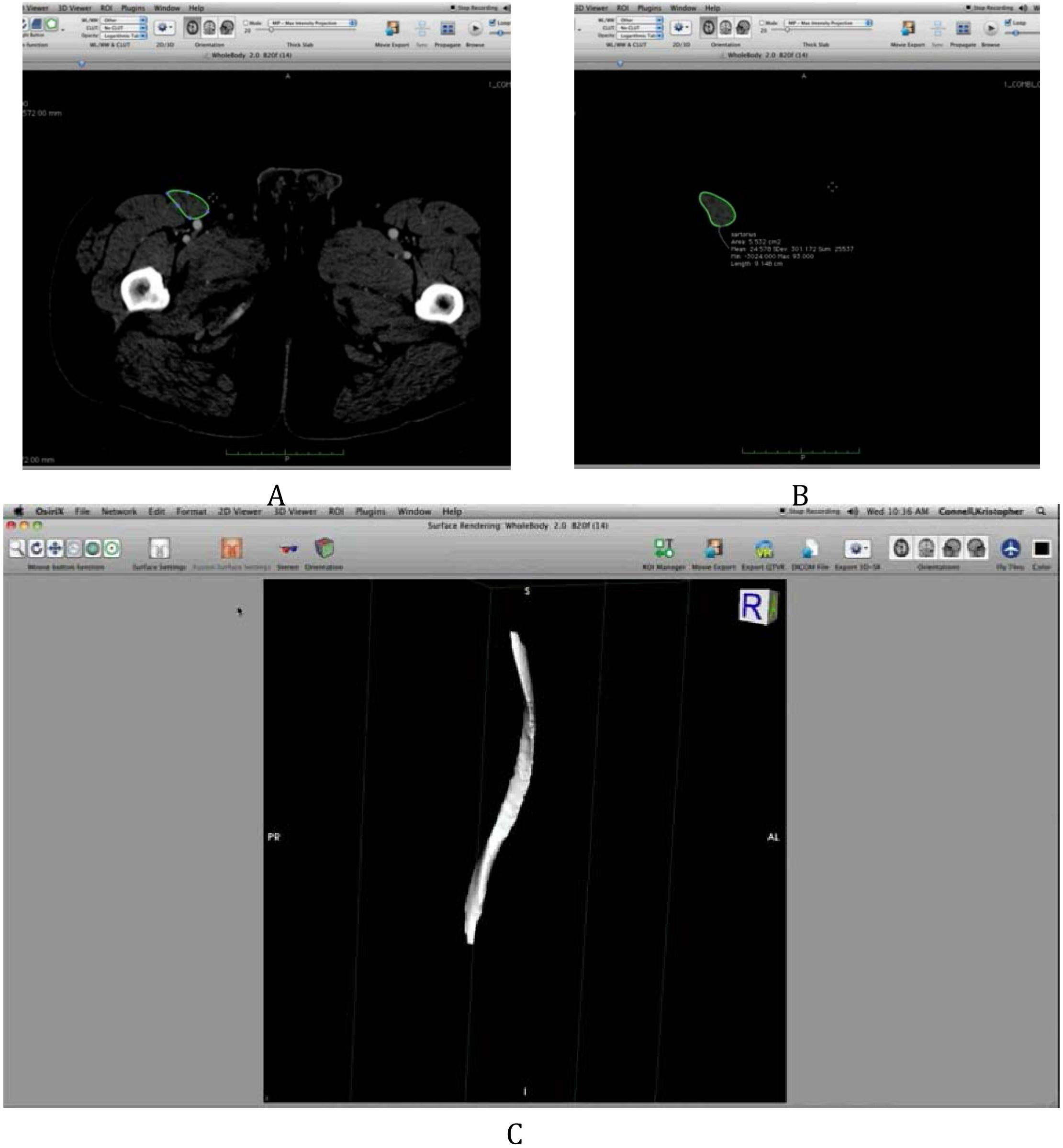


Figure 16: OsiriX Muscle Isolation Process- Sartorius

A) Tracing of the Muscle Body using ROIs **B)** Isolating the Muscle

C) Rendering Out the Muscle Using the 3D Surface Render

Once the bones and muscles were exported from OsiriX, the models were imported into an application called 3D-Coat so they could be retopologized for use in Maya and ultimately Unity 3. The raw models exported from OsiriX were incredibly high resolution, anywhere from 15,500 to 85,000+ faces. In order to run in a real-time render engine like Unity 3, the poly-count must be drastically reduced to increase the performance of the application. In normal animation, each frame is pre-rendered and then played back in a sequence like a traditional film reel. In real-time animation for games or 3D applications, the computer is performing the calculations while the user is interacting with the program, and if the poly-count is too high, it will severely impede the performance of the created application.

However, for 3D modeling and animation, the poly-count is not the only factor that needs to be considered in the construction of a model. The topology of the model, how the model is constructed by polygons, is also crucial to ensure that the model properly deforms during the animation process. I utilized 3D-Coat's Auto-Topo tool, which allowed me to define an approximate total poly-count, areas of the mesh that should be more dense (contain more polygons to preserve details) than others, and identify the general topology I wanted the model to have (Figure 17 A-C). Once I specified these parameters the program generated a new mesh based on the shape of the model exported from OsiriX (Figure 17D). The new model was then brought into Maya and edited to refine the topology. Also, due to the limits of the CT scan data, I had to modify the models to include the tendon attachments for each of the muscle bodies.

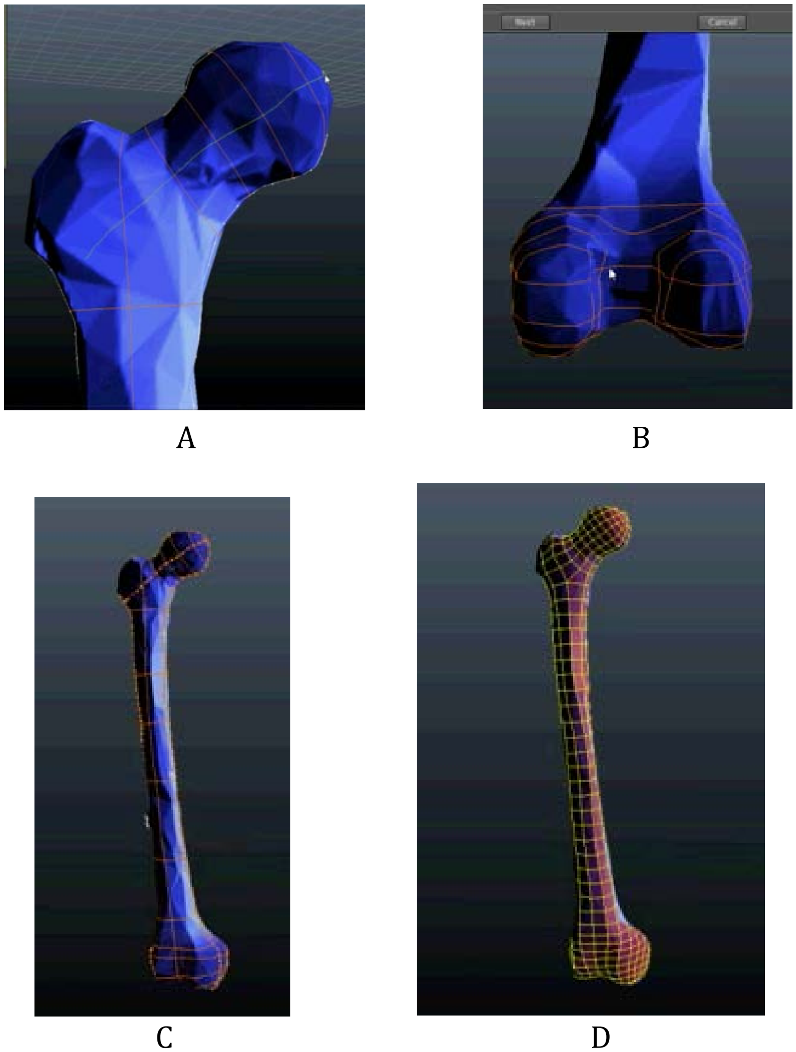


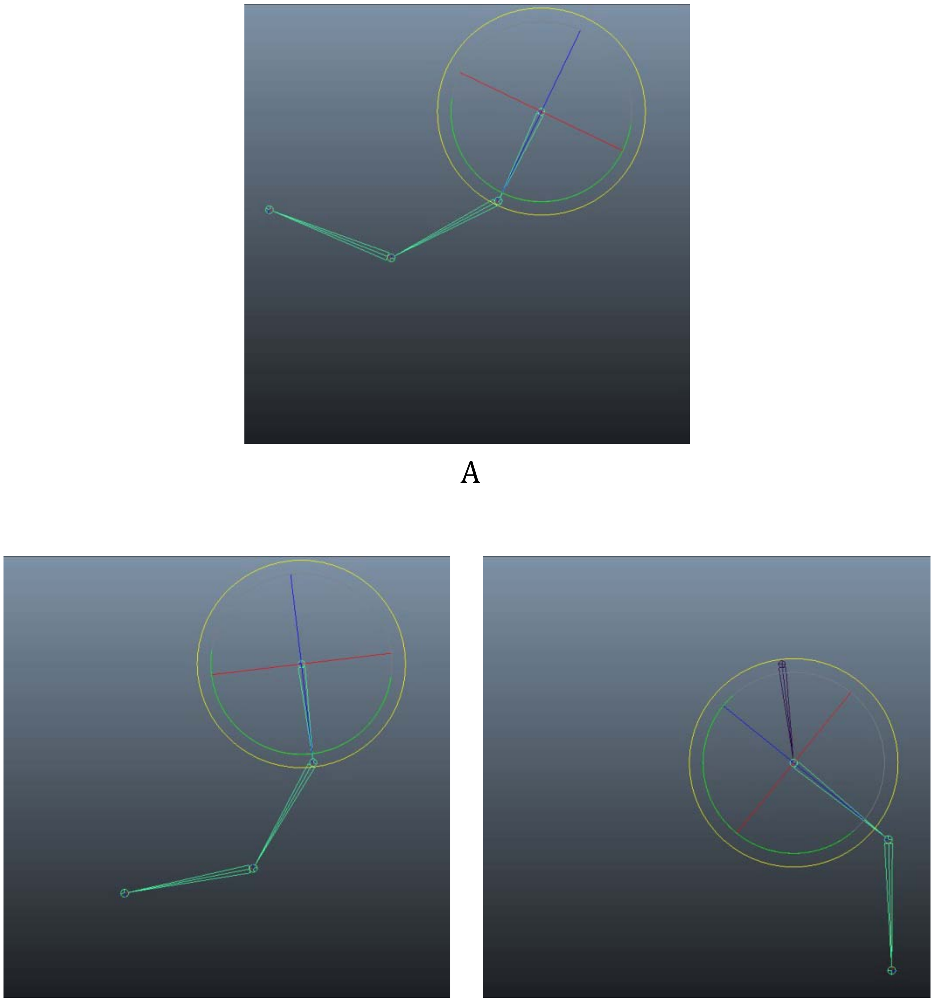
Figure 17: Retopology Process in 3D -Coat

A) Defining the Topology, Femoral Head **B)** Defining Topology, Medial/Lateral Condyles

C) Definint Topology, Femur **D)** New Mesh Generated By 3D Coat's AutoTopo Feature

Prior to this point in the process, the models I generated were entirely based on information derived from the CT scan data. In order to finish the modeling process and animate the motion of the muscles, I was forced to extrapolate from various reference sources. To ensure that my interpretations were correct, I again consulted Dr. Ebaugh. Our first round of review was to ensure the models were accurate, correcting any errors that occurred in either my modeling of the tendons or any anomalous muscle deformations caused by the position of the person during the CT scan process (i.e. joint rotation or muscle compression from laying in the machine).

Once the muscle models were approved, the skeleton and muscles had to be rigged for animation to allow the body to move and be controlled in the application. First, I created the rig for the skeletal system, ensuring the proper motion for the anatomical joints. Once that skeleton was created, additional rigging was added to facilitate the deformation of the muscles. Each muscle was controlled by multiple animation joint-chains (Figure 18). One chain stems from the insertion point of the muscle, and another from the origin point. The respective joint chains would meet in the middle of the muscle, allowing for control over the entire muscle. Certain muscles, such as the biceps femoris or the gastrocnemius, required additional joint chains, since they consisted of multiple separate muscle bodies that joined into single tendon body at the insertion points. While the quadriceps muscles (rectus femoris and vastus intermedius, lateralis, and medialis) merge together into a singular tendon at the patella, it was a conscious decision to separate those tendons to still allow each of those muscles to be isolated or deactivated based on the learning needs of the user.



A

B C

Figure 18: Joint Chains

A) Joint Chain Starting Position **B)** How Rotation of Top Joint in Chain Affects Lower Joints

C) How Rotation of Second Highest Joint Affects the Joint Chain

Once the rig was created, a set of controls was created to allow for manipulation of the body. For each of the anatomical joints, an FK setup was used so that each anatomical region could be moved separately. For the muscles, a series of spline IK systems and controllers were created. This allowed simpler manipulation of the various joint chains in each muscle compared to an FK configuration. This type of control setup was ideal for consultations with Dr. Ebaugh, allowing us to readily manipulate the muscle bodies and ensure the accuracy of the deformations.

Once the animations were completed and approved, I went through the process of baking the animation. Computer animation works by establishing a series of key frames to the transformation values (translate, rotate, and scale) of an object in the scene, and these key frames correspond to the major poses of the animation sequence. The computer will then interpolate the motion between each of those key frames, creating the animations in between. For real time rendering in a game or application, the practice is to bake the animation, or record the transformation values on every frame, so the computer does not have to calculate the motion, only read in a set of values.

Once the anatomical model was successfully integrated into Unity, I went through the process of refining the texture applied to the bones and muscles. To gain the proper texture reference material, I once again collaborated with Dr. Ebaugh and visited Drexel University's cadaver lab. While there, I was able to examine a cadaveric specimen of the models I was creating and take reference photographs. After acquiring the reference images, I brought the bone and muscle models into Pixologic's Zbrush and painted the textures onto the models and sculpted in additional details such as the definitions of muscle fibers. After I completed the sculpting and painting process, I could export a series of texture maps for each model that allowed me to apply the correct colors and a series of normal maps that gave the illusion of additional details on the models.

Integration

Three major factors needed to be considered during the creation of the anatomical model to ensure smooth integration from Maya to Unity. The first consideration, mentioned earlier, is poly-count. In real-time rendering, the number of polygons that make up each mesh is important. The higher density the mesh, the more detailed deformation you can get, but the harder the system has to work to render it. The faster the render engine can work, the higher frame rate the application can achieve, and the smoother the animations appear. So I had to find a balance of detail vs. performance when generating the models.

The second integration concern is an issue specific from Maya to Unity. In the rigging process, to replicate the shortening and widening of the muscle bodies, I built an aspect into the rig that would scale the joints. However, there is a default feature on Maya's animation joints called "Segment Scale Compensate." This feature allows for the animator to scale a joint without affecting the joints farther down the joint chain. However, this feature does not translate onto Unity. So any scaling animations will look different in Unity than in Maya as long as this feature is enabled. To ensure consistent animation/deformation between the two programs, this feature should be disabled prior to animating in Maya, especially if there are going to be scale values applied to the animation joints.

The last consideration I made was how the animations would be controlled in the application. I could either control the joint transformation values (rotate and scale) directly in Unity, creating a set of scripts that will transition between values as the sliders were adjusted, or create all of the animations in Maya and control the playing of the various animations in Unity. I chose the latter method, which allowed greater control over the deformations.

Limitations and Future Research

Due to the limited resources and overall scope of the project, certain considerations had to be made to ensure the creation of a quality, functional prototype. The timeframe of the project did not allow for the generation of the entire body's musculature, so I chose to focus my efforts on producing an accurate representation of a single joint. The limited budget of the project and difficulty of access to medical imaging technology also restricted the anatomical structures I could generate from medical data. As a result, the prototype focuses on the bones and muscles relevant to knee flexion and extension, the area extending from the tarsals to the pelvis, including the sartorius, gracilis, semimembranosis, semitendinosis, gastrocnemius (lateral and media heads), biceps femoris (short and long heads), vastus lateralis, vastus intermedius, vastus medialis, and rectus femoris. The remainder of the skeleton was modeled from source images to give a visual context to the anatomical information portrayed by the application.

There are a multitude of ways the prototype can be expanded and further developed that fell outside the scope of the project. First and foremost the rest of the musculoskeletal anatomy could be generated, allowing the user to explore the entire human body. Additional visuals could be added, such as the nervous and vascular systems.

To further develop a healthcare professional's diagnostic abilities, the addition of injury animations would be beneficial. Controls could be added to restrict the motion of a particular joint, muscle, or muscle group, allowing the user to observe how an injury could affect the joint motion (i.e. a ruptured or torn tendon).

Another feature that could be included in the design of the application would be a method for user reflection. As previously stated, in order to promote meaningful learning, an educational application needs to both present the user with information in a meaningful way and help the user reflect on what they have learned. This could be done by constructing a quiz section of the application. The quiz section would force them to either draw on the knowledge they have gained through the use of the application, or go back to the model and find the necessary information.

Additional refinement of the visuals and interface could be made through future testing of the application. Potential prototypes could be given to anatomy students and medical professionals to provide a quantitative analysis of effectiveness of any aspect of the interface and a qualitative examination of the look and feel of the visual design.

Once these elements were refined, an important future consideration would be to develop the application for additional platforms, such as iOS or Android devices. Due to the scope of the project, I limited development to the creation of a desktop application. However, with the continual growth in popularity of mobile devices and tablets, development for these platforms would greatly expand the use and effectiveness of the application.

Conclusion

Overall this was a successful project that involved the creation of a novel educational application prototype. The prototype sought to accomplish two objectives: create an effective application and develop a pipeline to create accurate anatomical models from medical data that could then be utilized in a real-time render engine.

The main goal of the application design was to give the user as much control over the experience as possible. This level of control allows for the range of learner types, Serialistic/Holistic, Convergent/Divergent, and Flexible/Focused thinkers, to cater the experience to their most effective learning type. They can proceed through the application however they wish. Creating an interface that effectively presents the user with the visuals and information allows for the cognitive load of the overall learning task to be lowered. Leveraging the qualities of digital media allowed me to present the information in multiple modalities, providing an effective experience for both verbalizers and imagers, and give the user the freedom to explore the information in whatever progression they so choose. All of these factors came together to create an environment that promoted active, critical learning experience as well as an effective method of reflection.

The development of the pipeline was the most time consuming aspect of the project. There were many situations where, after a considerable amount of research and development on a particular problem, I would discover a solution that was later revised due to an unforeseen development later in the pipeline. However, by the end of the process, I feel I have established a system that can be integrated into a production pipeline and yield suitable results.

References

[1-12, 16, 17]

[1] R. S. McCuskey, "The Importance of Anatomy in Health Professions Education and the Shortage of Qualified Educators," *Academic Medicine*, vol. 80, p. 3, 04/01/2005 2005.

[2] K. Sugand, *et al.*, "The Anatomy of Anatomy: A Review for Its Modernization," *Anatomical Sciences Education*, vol. 3, pp. 83-93, Mar-Apr 2010.

[3] 3D4Medical, "Muscle Systems Pro II," in *Professional Nova Series*, 2 ed: 3D4Medical, 2011, p. An interactive anatomy application for the iPad.

[4] P. Pictures, "ANATOMY.TV Series," ed: Primal Pictures, 2011.

[5] S. N. Biasutto, *et al.*, "Teaching anatomy: Cadavers vs. computers?," *Annals of Anatomy - Anatomischer Anzeiger*, vol. 188, pp. 187-190, 2006.

[6] S. Cairncross and M. Mannion, "Interactive multimedia and learning: Realizing the benefits," *Innovations in Education and Training International*, vol. 38, pp. 156-164, May 2001.

[7] W. V. R. L. Drake, A.W.M Mitchel, H.Gray, *Gray's Anatomy for Students*, *2nd ed*. Philadelphia, PA: Elsevier/Churchill Livingstone, 2005.

[8] N. Hedin, "Experiential Learning: Theory and Challenges," *Christian Education Journal*, vol. 7, pp. 107-117, Spring2010 2010.

[9] J. P. Gee, *What Video Games Have to Teach Us about Learning and Literacy*. Gordonsville, VA, USA: Palgrave Macmillan, 2003.

[10] J. Fowler, "Experiential learning and its facilitation," *Nurse Education Today*, vol. 28, pp. 427-433, 2008.

[11] J. Sweller, "Cognitive load theory, learning difficulty, and instructional design," *Learning and Instruction*, vol. 4, pp. 295-312, 1994.

[12] F. Kirschner, *et al.*, "Cognitive load theory and multimedia learning, task characteristics and learning engagement: The Current State of the Art," *Computers in Human Behavior*, vol. 27, pp. 1-4, 2011.

[13] OsiriX, "OsiriX Imaging Software."

[14] J. Arvo and K. Novins, "Iso-contour volume rendering," presented at the Proceedings of the 1994 symposium on Volume visualization, Tysons Corner, Virginia, United States, 1994.

[15] S. M. Elizabeth Brainerd. (2011, January). *Creating 3D models with OsiriX*. Available: https://wiki.brown.edu/confluence/display/ctx/Creating+3D+models+with+OsiriX

[16] N. Cross, "Styles of learning, designing and computing," *Design Studies*, vol. 6, pp. 157-162, 1985.

[17] F. H. Netter, *Atlas of Human Anatomy, 5th ed.*, 5th ed. Philadelphia, PA: Saunders Elsevier, 2011.